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Effect of basalt on the mechanical and thermal behavior of a lightweight concrete based on *Typha australis*

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This article examines the impact of integrating basalt aggregates into concrete based on *Typha australis* for housing applications. We conducted an experimental study focusing on mechanical and thermal characterization to analyze the influence of basalt aggregates compared to the results of previous work on *T. australis* concrete without basalt. The results indicate that both density and mechanical resistance to compression decrease with the dosage of Typha, yet the values obtained are significantly higher than those of concrete without basalt. Additionally, thermal resistance increases with the Typha dosage. However, for low Typha dosages, the thermal resistance is slightly higher than that of concrete without basalt, whereas for high dosages, it is slightly lower. Nevertheless, this finding allows for a reduction in the building's thermal load and an enhancement of thermal comfort. However, it's important to note that the mechanical strength remains relatively low for a high-strength structure.

Key words: Lightweight concrete, *Typha australis*, basalt aggregates, density, mechanical resistance, thermal resistance, thermal load, thermal comfort.

INTRODUCTION

Basalt is a volcanic rock resulting from magma that cools quickly upon contact with water or air. It constitutes the primary component of the upper layer of the oceanic crust and is utilized as aggregates to enhance the mechanical strength of concrete for building construction (Azibert, 2016; Adam et al., 2021). Given the challenges associated with global warming, there is increasing concern about the use of cement-based materials. The preference for concrete constructions is primarily driven by urban planning, modernism, and aesthetics. However, these constructions are energy-intensive and are influenced by the use of household appliances,

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NOMENCLATURE: **C,** Specific heat capacity, (J.kg-1..K-1); **E,** Thermal effusivity, ($J.m^{-2}.K^{-1}.s^{-1/2}$); **F,** Maximal force (N); **S,** area of sample (m^2); **λ,** thermal conductivity ($W.m^{-1}.K^{-1}$); **ρc,** Volumetric heat capacity, ($J.m^{-3}.K^{-1}$); **ρ,** density ($kg.m^{-3}$); **σ,** mechanical strength (Mpa).

consequently escalating the overall energy costs of the building. Therefore, there is a need to explore solutions that combine modernism and aesthetics with energy efficiency in buildings, along with the enhancement of thermal comfort through the search for effective thermal insulation materials (Bernard, 2014; Labouda et al., 2020).

Typha australis, an aquatic plant found in streams, rivers, lakes, and ponds, significantly disrupts the exploitation of agricultural resources and degrades water quality. Its impact on socio-economic activities necessitates various eradication attempts, aiming to promote its utilization in specific economic sectors (Ahmadou et al., 2020). Typha australis, akin to "bio-sourced" materials (Bernard, 2014), finds application in the construction sector for the production of thermal insulation materials (Cerezo, 2005; Marthe et al., 2011; Azibert et al., 2016; Diaw et al., 2016; Azibert et al., 2021). Once cut and dried, the typha plant becomes lightweight and highly porous (Clement et al., 2023). Consequently, it is employed as a lightweight aggregate in the building sector (Ababacar et al., 2021) with the goal of reducing the thermal load. However, its mechanical resistance to compression is low.

To enhance the mechanical resistance of concrete, we introduced rigid basalt aggregates into a mortar based on *Typha australis*, aiming to compare the results with our previous work on Typha concrete without basalt (Azibert et al., 2016). Within the scope of this study, we produced a series of test specimens that incorporated Typha aggregates, basalt aggregates, and fine sand. Following the determination of the basalt granulometry, we proceeded with the manufacturing of the specimens for mechanical and thermal tests.

Figure 1. Basalt aggregates.

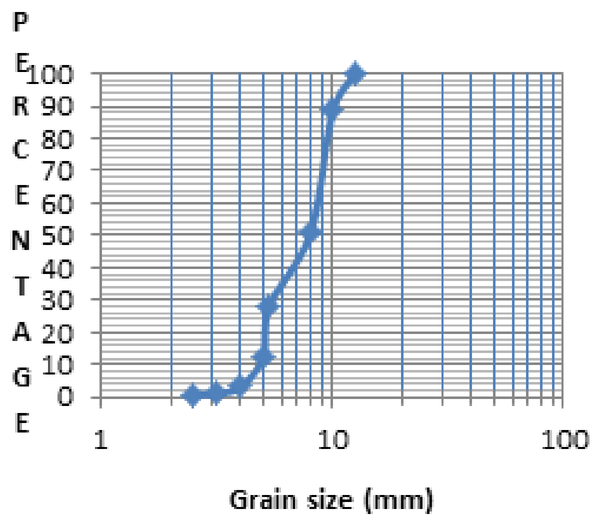

Figure 2. Grain size curve of basalt aggregates.

MATERIALS AND METHODS

Basic materials used

In this study, we utilized fine dune sand (0/2 mm), CEM II/B-M 32.5R cement, and *Typha australis* aggregates (1/20 mm) with an absolute density of 144.95 kg/m³ and an intergranular porosity of 24.23%. Additionally, basalt aggregates (2/12 mm) with an absolute density of 2850 kg/m³ and a thermal conductivity of 1.6 $W.m^{-1}.K^{-1}$ were employed (Azibert, 2016; Adam et al., 2021; Azibert et al., 2016). Figure 1 displays the basalt aggregates, while Figure 2 illustrates the grain size curve. We prepared a series of samples with cement-to-sand mass ratios of 0.3 (C/S=1/3) and a cement-to-water mass ratio of 1.6 (C/W=1.6). The Typha content was varied from 0 to 2.5% in increments of 0.5% relative to the total mass of the specimen before adding water. Basalt aggregates were also introduced. For two measures of basalt sand, one measure of fine dune sand was used. The mass composition of the constituents before adding water is presented in Table 1.

Experimental methods

Manufacturing of specimens

The Typha aggregates were moistened before their incorporation into the cement mortar, which had been pre-mixed in a tank [6]. This step is crucial as the humidity of the Typha aggregates, during the addition of mixing water, facilitates proper setting of the cement. Subsequently, the mixture is introduced into molds. For mechanical tests, cylindrical molds with a diameter of 11 cm and a height of 22 cm are used, while for thermal tests, rectangular prism molds measuring 10 × 10 × 3 cm are employed (Figure 3).

Measurement of thermal resistance

We used an experimental device of the hot plane type for the measurement of the thermal properties. This device is essentially made up of a stabilized power supply, which is a TTI brand direct current generator (THURBY THANDAR INSTRUMENTS) 32V-3A, which allows the voltage applied to the probe to be fixed, an isothermal block which is connected to the probe by type K thermocouples which are made up of 0.005mm diameter wires, and an AGILENT BENCHLINK DATALOGGER brand data acquisition

Table 1. Mass composition of the constituents (kg).

%Typ	0%	0.5%	1%	1.5%	2%	2.5%
Basalt sand	16.3	14.2	13.4	12.4	10.1	9.2
Fin dune sand	8.2	7.1	6.8	6.4	5.5	5.5
Cement	8.2	7.1	6.8	6.4	5.5	5.5
Typha	0	0.14	0.27	0.38	0.43	0.52
Water	4.6	3.7	4.1	4.1	3.8	4.0
C/W	1.78	1.92	1.66	1.56	1.45	1.38
C/S	0.33	0.33	0.34	0.34	0.35	0.37

Figure 3. Samples for (a) mechanical strength, (b) thermal characteristics.

Figure 4. General view of the hydraulic press.

module 34970A which allows measurements to be recorded and connected to a computer for processing the information. The following Figure 6 presents the photograph of the entire experimental setup. The measurement of thermal resistance was determined using an asymmetrical hot plane type device with insulated rear face (Azibert, 2016; Azibert et al., 2016). The sample is placed between two polystyrene blocks and the whole is inserted between two aluminum insulated blocks as shown in Figure 7. A thin electrical heating resistor is inserted between a sample and a thermal insulator. For the transfer to be assumed to be unidirectional, the surface of the material to be characterized must be flat and equal to that of the heating probe, and that the lateral losses by convective exchange are negligible. A thermocouple is placed on the front side of the sample; that is to say between the electrical heating resistance and the thermal insulator. During the measurement time, the thickness of the sample must be well chosen so that the hypothesis of the semi-infinite medium is verified (Jannot, 2011). Figure 7 shows the simplified device. The hot plate transient method allows measurement of the effusivity (E) and simultaneously the conductivity (λ). From the measurement of the thermal effusivity (E), the thermal capacity (ρc) can be determined (Equation 2).

$$E = \sqrt{\lambda \rho c} \qquad (2)$$

Measurement of strength

The mechanical compressive strength of the cylindrical specimens was determined using a hydraulic press, TINUS OLSEN brand, equipped with a dial graduated from 0 to 800kN (Azibert, 2016) (Figure 4). Each graduation on the measurement scale corresponds to 1 kN. The crosshead moves at a variable speed, with a common value of 5 mm/min (Cerezo, 2005). Figure 5 depicts the simplified device for measuring the mechanical resistance to compression. The measurements were conducted after 28 days of curing. Equation 1 is utilized to determine the mechanical strength of the sample.

$$\sigma = \frac{F}{S} \qquad (1)$$

Where σ is the mechanical strength (Pa), F is the maximal force applied (N), and S is the area of the sample (m^2).

EXPERIMENTAL RESULTS

Density of concrete

The variation of concrete density as a function of the percentage of typha is shown in the following Table 2 and Figure 8.

Mechanical strength

The results of the measurements of the mechanical

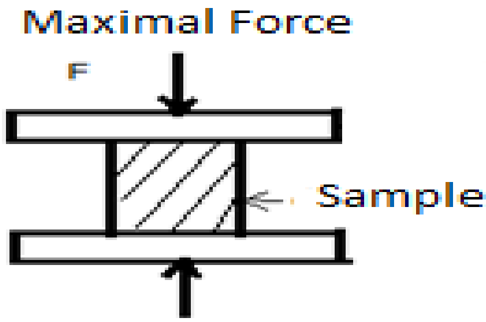

Figure 5. Strength measurement.

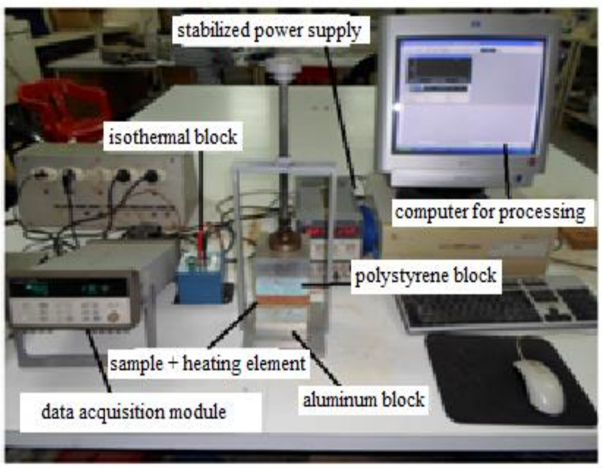

Figure 6. General view of the experimental device for the asymmetric hot plane method.

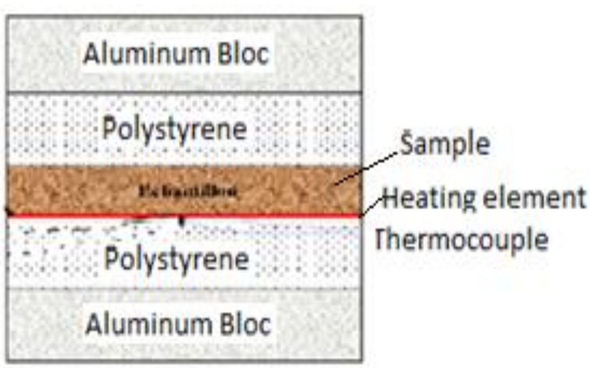

Figure 7. Experimental design of asymetric hot plane (Jannot, 2011).

compressive strengths of this concrete are grouped in the following Table 3. The evolution of the mechanical compressive strengths of the concrete according to the percentage of typha, is represented in the following Figure 9.

Thermal properties

The results of measurements of the thermal properties are grouped in the following Table 4. The following Figure 10 illustrates the evolution of the thermal conductivity according to the dosage in typha.

DISCUSSION

The results reveal that the concrete density decreases with the increasing dosage of Typha due to the low density of Typha aggregates. However, this density remains significantly higher than that of concrete without basalt (Azibert, 2016; Azibert et al., 2016), and the difference remains almost constant with the Typha dosage. Basalt, therefore, contributes to increasing the concrete density, categorizing it as light, especially for high Typha dosages. It's worth noting that lightweight concretes typically have a density ranging from 300 kg/m³ to 1800 kg/m³ (Azibert, 2016).

The results also indicate an exponential decrease in mechanical resistance to compression with the dosage of Typha. However, the values obtained are notably superior to those of concrete without basalt, as observed in our previous work (Azibert et al., 2016). Typha, being a very light and porous plant (Clement et al., 2023), influences the mechanical resistance of concrete. For instance, at 0% Typha, the resistance value for concrete with basalt was 21.7 MPa, while that of concrete without basalt was 13.95 MPa, representing an increase of 64.3%. Similarly, at 2.5% Typha, the resistance value for concrete with basalt was 1.16 MPa, compared to only 0.8 MPa for concrete without basalt, resulting in a 69% increase.

Despite the enhancement in mechanical strength, this concrete is not suitable for high-strength structures. However, it proves to be suitable for structures requiring low or moderate resistance, as it allows a wall of three meters in height to support its own load. The inclusion of basalt significantly improves the mechanical compressive strength of Typha concrete.

Furthermore, the results indicate that the thermal conductivity of concrete decreases with the dosage of Typha. Specifically, the thermal conductivity of concrete with basalt at 0% Typha is 0.98 W/m.°C, while that of concrete without basalt is 1.006 W/m.°C (Azibert, 2016; Azibert et al., 2016). The integration of basalt into the mortar introduces mesoscopic porosities (Cerezo, 2005), the proportion of which affects the overall conductivity of the composite. Therefore, concrete with basalt exhibits a lower conductivity of 0.98 W/m.°C.

However, as the Typha dosage increases, the

Table 2. Values of the density of concrete.

%Typha	0%	0.5%	1%	1.5%	2%	2.5%
ρ(kg/m^3)	2319	2207	2118	2028	1920	1856

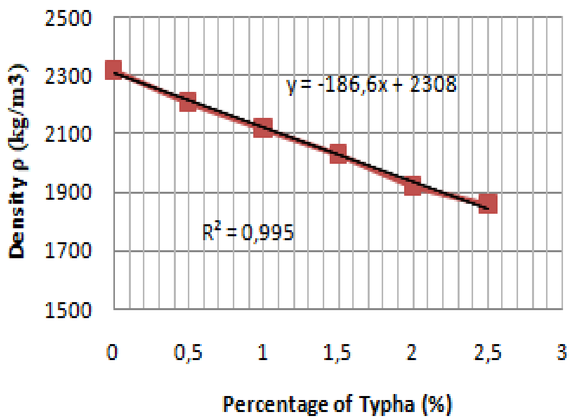

Figure 8. Variation of concrete density, according to the dosage in typha.

Table 3. Values of the mechanical compressive strengths.

Typha (%)	0	0.5	1	1.5	2	2.5
σ(MPa)	21.7	12.1	6.1	4	2.3	1.16

conductivity decreases and reaches 0.55 W/m.°C for a Typha dosage of 2.5%. This value is slightly higher than the result obtained in our previous work on Typha concrete without basalt, where the value was 0.51 W/m.°C (Azibert et al., 2016). At 2.5% Typha, concrete with basalt has a slightly lower thermal resistance compared to that without basalt.

The combination of non-deformable rigid aggregates and porous, deformable lightweight aggregates in a cement mortar contributes to reducing the total porosity of the concrete during implementation. The light and porous aggregates (Clement et al., 2023), permeable to water, deform under the action of contact with the rigid and impermeable aggregates that are non-deformable. The decrease in the total porosity of the concrete affects the conductivity of the composite. This is why the conductivity of the concrete without basalt is 0.51 W/m.K, while that with basalt is 0.55 W/m.K. This value also contributes to lowering the thermal load of buildings.

Conclusion

This study demonstrates that the mechanical resistance

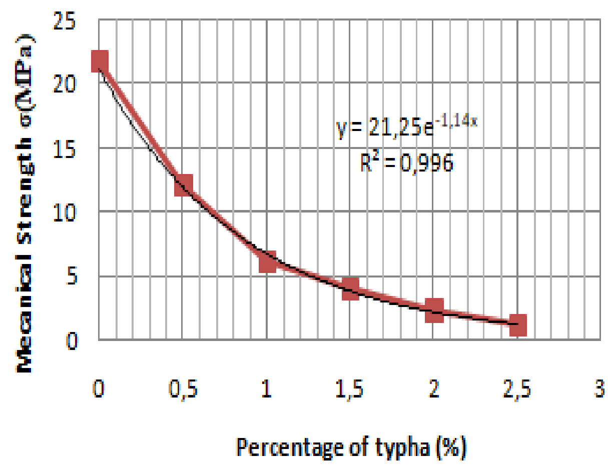

Figure 9. Evolution of the mechanical strength as a function of dosage of typha.

Table 4. Measurement results of thermal properties.

% Typha	0%	0.5%	1%	1.5%	2%	2.5%
E	1406	1365	1288.6	1165.7	1050	970
λ	0.98	0.93	0.84	0.74	0.61	0.55
ρc.10^{-3}	2017	2003	1976	1836	1807	1710
C	926.75	972.55	1001.7	963.12	1017	968

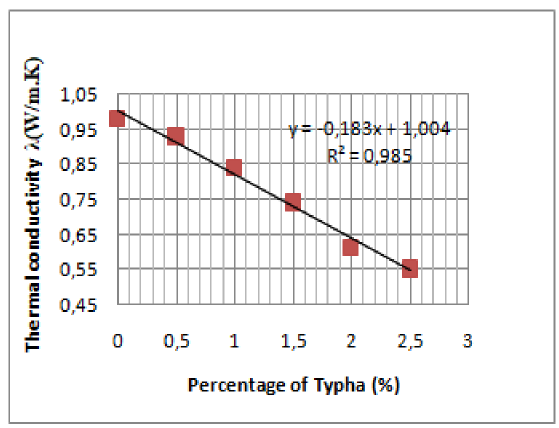

Figure 10.: Evolution of the thermal conductivity as a function of dosage of typha

to compression and the density of concrete decrease with the dosage of Typha due to the porosity resulting from the incorporation of lightweight Typha australis aggregates in the mortar. However, the introduction of basalt aggregates into Typha concrete leads to a significant increase in both density and mechanical resistance to compression when compared to concrete without basalt. Moreover, the thermal resistance of concrete with basalt increases with the dosage of Typha. For low Typha dosages, the thermal resistance of concrete with basalt is notably higher compared to that without basalt. However, for high doses of Typha, this resistance is slightly lower than that without basalt. The results highlight that the use of basalt aggregates enhances the mechanical resistance and slightly decreases the thermal resistance of Typha australis concrete. Despite the reduction in thermal resistance, the obtained thermal resistance values still contribute to lowering the thermal load of the building and improving thermal comfort. It is important to note, however, that the mechanical resistance remains low for structures requiring high strength.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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